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WORKSHOP ON
COLD FUSION
PHENOMENA

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WORKSHOP ON COLD FUSION PHENOMENA

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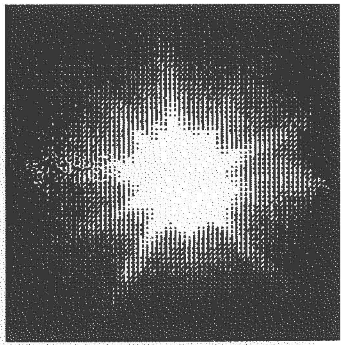

WORKSHOP ON
COLD FUSION
PHENOMENA

MAY 23-25, 1989
SANTA FE, NEW MEXICO

AGENDA

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WORKSHOP CO-CHAIRMAN

Dr. Norman Hackerman
The Welch Foundation
Houston, TX

Dr. J. Robert Schrieffer
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and Hydrogen Research
Texas A&M University
College Station, TX

Dr. Anthony L. Turkevich
Enrico Fermi Institute
University of Chicago
Chicago, IL

AGENDA

WORKSHOP ON COLD FUSION PHENOMENA

May 22–25, 1989

SWEENEY CENTER, SANTA FE, NM

MONDAY, MAY 22

Workshop participants arrive in Santa Fe

4:00 – 8:00	Registration and badge issue at Eldorado Hotel—Hospitality room available at Eldorado Hotel

TUESDAY, MAY 23

7:30 – 8:00	Arrival at Sweeney Center	
8:00 – 8:30	Late Registration	
8:30 – 9:00	Preliminary Remarks	Reed J. Jensen
–	Welcome	Sig Hecker
–	Introduction of Workshop	Norman Hackerman
9:00 – 12:00	First Plenary Session (A)— **Integrated Experiments** Moderator: **Reed J. Jensen** Los Alamos National Laboratory	
9:00 – 9:30	Evidence for Excess Heat Generation Rates During Electrolysis of D_2O in LiOD Using a Palladium Cathode – A Microcalorimetric Study (Invited Talk)	A.J. Appleby, S. Srinivasan, O.J. Murphy, C.R. Martin Texas A&M
9:30 – 9:50	Neutron Emission and the Tritium Content Associated with Deuterium Loaded Palladium and Tritium Metals	K.L. Wolf, N. Packham, J. Shoemaker, F. Cheng, D. Lawson Texas A&M
9:50 – 10:20	BREAK – Refreshments Available	

		G.A. Wurden LANL
10:20 –	Electrochemical “Cold Nuclear Fusion” Attempts at IPP	H.S. Bosch, J. Gernhardt, G. Janeschitz F. Karger, J. Perchermeier Max Planck Institut für Plasma Physic FR Germany
10:40 –	Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes	D. Albagli, V. Cammarata, M. Schloh, M.S. Wrighton X. Chen, C. Fiore M. Gaudreau, D. Gwinn, P. Linsay, S.C. Luckhardt, R. Parker, R. Petrasso K. Wenzel, R. Ballinger I. Hwang MIT
11:00 –	In Search of Nuclear Fusion in Electrolytic Cells and Metal/Gas Systems	D.R. McCracken, J. Paquette, R.E. Johnson, N.A. Briden W.G. Cross, A. Arjena, A.M. Lone, D.C. Tennant, W.J.L. Buyers Chalk River Labs Ontario, Canada
11:20 –	LUNCH/POSTER SESSION	
1:30 – 5:00	Second Plenary Session (B)— **Integrated Experiments** (Cont'd) Moderator: **Fred Morse** Los Alamos National Laboratory	
1:30 –	Search for Neutrons from Cold Fusion in Pd-D	R.S. Raghavan, L.C. Feldman M.M. Broer, J.S.Kraus, A.C. James, D.W. Murphy AT&T Bell Labs
1:50 –	Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in D_2O	Nathan S. Lewis, Charles A. Barnes Cal Tech
2:10 –	Search for Fusion in Deuterated Transition Metals: Dynamical Pressures Above 1 Megabar	F.M. Mueller, K.A. Johnson, W.J. Medina, A.R. Mantheia, C.L. Talcott, E.K. Storms J.W. Shaner, B.L. Freeman J.E. Vorthman, M.M. Fowler LANL

2:30 –	Tests for "Cold Fusion" in the Pd-D_2 and Ti-D_2 Systems at 350 MPa and 195-300 K	J.G. Blencoe, M.T. Naney, D.J. Wesolowski ORNL
2:50 –	Measurements of Heat, Neutron and γ Flux Induced by μ Stopped in Deuterium Saturated Targets	M.Chen, S. Steadman, C.Fiore, M. Gaudreau, S. Luckhardt, R. Parker, R. Crooks, M. Schloh, D. Albagli, V. Cammarata, M. Wrighton MIT R. Debbe, D. Lowenstein BNL
3:10 –	Electrochemical Experiments in Cold Nuclear Fusion	J.F. Ziegler, T.H. Zabel, J.J. Cuomo, V.A. Brusic, G.S. Gargill III, E.J. O'Sullivan, A.D. Marwick IBM Rsch. Div., Thomas J. Watson Research Center
3:30 –	BREAK – Refreshments Available	
	Physics of Fusion Reaction	
4:00 –	Nuclear Reactions and Screened-Coulomb Fusion Rates	G.M. Hale, R.D. Smith, T.L. Talley LANL
4:20 –	Molecular Dynamics Simulation of $PD_{1.1}$: How Close Can Deuterons Get?	Peter M. Richards SNL
4:40	Conditions Leading to the Production of Cold Fusion Neutrons	M. Gajda, G. Harley, J. Rafelski Univ. of Arizona
5:00 – 5:30	BREAK – Walk to Eldorado Hotel	
5:30 – 7:00	Reception at Eldorado Hotel	
7:00 – 7:30	Return to Sweeney Center	
7:30 – 9:30	Discussion Period with Presenters	J. O'M. Bockris

WEDNESDAY, MAY 24

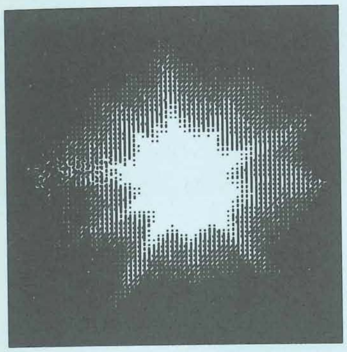
7:30 – 8:00	Arrival at Sweeney Center	
8:00 – 12:00	Third Plenary Session (C)— **Neutron- & Gamma-Ray Spectroscopy** Moderator: **C. A. Barnes** Cal Tech	
8:00 –	Cold Nuclear Fusion in Condensed Matter: Recent Results and Open Questions (Invited Talk)	S.E. Jones BYU

8:30 –	Experimental Evidence for Cold Nuclear Fusion in a Measurement Under the Gran Sasso Massif	A. Bertin, M. Bruschi, M. Capponi, S. DeCastro, U. Marconi C. Moroni, M. Piccinini, N. Semprni-Cesari, A. Trombini, A. Vitale, A. Zoccoli Instituto Nazionale Di Fisica Nucleare Italy
		J.B. Czirr, G.L. Jensen S.E. Jones, E.P. Palmer BYU
8:50 –	The Measurement of Neutron Emission from Ti Plus D_2 Gas	H.O. Menlove, M.M. Fowler E. Garcia, A. Mayer, M.C. Miller, R.R. Ryan LANL
		S.E. Jones BYU
9:10 –	Neutron Emission from a Titanium-Deuterium System (Invited Talk)	A.De Ninno, A. Frattolillo, G. Lollobattista, L. Martinis, M. Martone, L. Mori S. Podda, F. Scaramuzzi Centro Ricerche Energia Frascati Italy
9:40 –	Upper Limits on Emission Rates of Neutrons and Gamma-Rays from "Cold Fusion" in Deuterided Metals	M. Gai, S.L. Rugari, R.H. France, B.J. Lund, Z. Zhao Yale
	(Invited Talk)	A.J. Davenport, H.S. Isaacs, K.G. Lynn BNL
10:10 –	BREAK – Refreshments Available	
10:40 –	Lack of Neutron and Gamma Radiation from PPPL's Cold Fusion Experiments	H.Hsuan, D. Manos, S. Cowley, R. Motley, L. Roquemore, T. Saito, J. Timberlake, W. Ayeres, T. Bennett, M. Bitter E. Cecil, S.C.J. Cuthbertson, H.F. Dylla, H. Furth, L. Grisham, H. Hendel, K. Hill, R. Kulsrud, D. Meade, S. Medley, D. Mueller, E. Nieschmidt, R. Shoemaker, J. Thomas Princeton University
11:00 –	An Attempt to Measure Characteristic X-Rays from Cold Fusion	R. Fleming,F. Donahue, S. Mancini,G. Knoll, B. Heuser Univ. of Michigan

11:20 –	LUNCH/POSTER SESSION	
1:30 – 5:00	Fourth Plenary Session (D)— **Calorimetry**	
	Moderator: **Anthony Turkevich** University of Chicago	
1:30 –	Title Unknown at Printing (Invited Talk)	R.A. Huggins Stanford University
2:00 –	Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells	N.A. Godshall, E.P. Roth, M.J. Kelly, T.R. Guilinger, R.I. Ewing SNL
2:20 –	The Possibility of Evaporation Dominating "Cold Fusion" Power Balance Calculations	A.E. Pontau SNLL
2:40 –	Calorimetric Measurements on Electrochemical Cells with Pd-D and Pd-H Cathodes	L. Redey, K.M. Myles, D. Dees, M. Krumpelt, D.R. Vissers ANL
3:00 –	Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis	D.E. Stilwell, M.H. Miles Naval Wpns. Cntr.
3:20 –	BREAK – Refreshments Available	
	Physics of Fusion Reactions–II	
4:00 –	Seven Chemical Explanations of the Fleischmann-Pons Effect	J.O'M. Bockris, N. Packham, O. Velev, G. Lin, M. Szklarzcyck, R. Kainthla Texas A&M
4:20	Evidence Against Condensed Matter Fusion Induced by Cosmic-Ray Muons	K. Nagamine, T. Matsuzaki, K. Ishida, S. Sakamoto, Y. Watanabe, M. Iwasaki, H. Miyake, K. Nishiyama, H. Kurihara, E. Torikai, T. Suzuki, S. Isagawa, K. Kondo University of Tokyo
4:40 –	DINNER/POSTER SESSION	
5:30 – 7:00	Optional, No-Host Buffet at Eldorado Hotel	
7:00 – 7:30	Return to Sweeney Center	
7:30 – 9:30	Discussion Period with Presenters	M. Broer

THURSDAY, MAY 25, 1989

7:30 – 8:00	Arrival at Sweeney Center	
8:00 – 12:00	Fifth Plenary Session (E)— **Applicable Condensed-Matter Physics, Applicable Electrochemistry, Analytical Chemistry of Appropriate Products** Moderator: **Johann Rafelski** University of Arizona	
8:00 –	PAC Studies of Electrolytically Charged Metal Cathodes	G.S. Collins, S.L. Shropshire, Jiawen Fan Washington State Univ.
8:20 –	Interaction of Deuterium with Lattice Defects in Palladium	F. Besenbacher,B.B. Nielsen, S.M. Myers,P. Nordlander, J.K. Norskov University of Aarhus Denmark
8:40 –	Search for Cold Fusion in Superstoichiometric Palladium Deuteride Using Ion Implantation	S.M. Myers,D.M. Follstaedt, J.E. Schirber,P.M. Richards SNL
9:00 –	Tritium Enrichment in the Electrolysis of D_2O	J. Bigeleisen State Univ. of NY Stony Brook, NY
9:20 –	Nuclear Fusion from Crack-Generated Particle Acceleration	F.J. Mayer,J.S. King, J.R. Reitz FJM Assoc., Univ. of Michigan Ford Motor Rsch. Lab
9:40 –	Search for 0.8 MeV ^{3}He Nuclei Emitted from Pd and Ti Exposed to High Pressure D_2	S.W. Barwick,P.B. Price, W.T. Williams UC–Berkeley
10:00 –	BREAK – Refreshments Available	
10:30 –	Workshop Summary/Wrap-Up	R. Schrieffer, N. Hackerman
12:00 –	Workshop Concludes	



WORKSHOP ON
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MAY 23-25, 1989
SANTA FE, NEW MEXICO

MEETING ABSTRACTS
Session A

Sponsored by Los Alamos National Laboratory
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EVIDENCE FOR EXCESS HEAT GENERATION RATES DURING ELECTROLYSIS OF D_2O IN LiOD USING A PALLADIUM CATHODE - A MICROCALORIMETRIC STUDY

Supramaniam Srinivasan*, Young Jin Kim*,
Oliver J. Murphy*, Charles R. Martin** and A. John Appleby *

*Center for Electrochemical Systems and Hydrogen Research
Texas Engineering Experiment Station
and
**Department of Chemistry
Texas A&M University
College Station, Texas 77843

The "cold fusion" announcement by Professors Martin Fleishmann and Stanley Pons on March 23, 1989, evoked great excitement and was a stimulation for scientists all over the world to reproduce their results. Microcalorimetric investigations were commenced in our laboratory with the objective of measurement of the excess heat generation rates reported by these scientists. The rationale for selection of the microcalorimetric techniques were: (1), the high sensitivity of microcalorimeters using thermoelectric measuring principles; (2), the successful use of microcalorimeters for measurement of heat generation rates in the 1μW to 8W range to predict self discharge rates of, for example, pacemaker batteries with predicted lifetimes of over ten years; and the rates of slow corrosion processes; and (3), the possibility of using small Pd electrodes (short, thin wires, small spheres) to minimize (i) the time required for maximum absorption of deuterium by electrochemical charging; (ii) the charging input power; and (iii) the consequent low input power requirements at the high current densities at which anomalous heating was observed.

A Tronac(Model 350) Microcalorimeter, refurbished by Hart Scientific Instruments, was used in this work. The basic components of this equipment are (1) stainless steel test and control cells (5 x 5 x 1 cm^3) which are snugly fitted into an aluminum block sink; (2) water reservoir, external to the aluminum block maintained at a constant temperature; and (3) thermoelectric sensors surrounding the test and control cells. The measurements are based on the Seebeck effect: A voltage develops between the hot (test) and cold (control) junctions, which is a measure of the heat flux.

Several tests and control experiments were carried out to determine the excess heat generation rates. These experiments consisted of:

1. Control Experiment - charging of Pd wire (0.5 mm diameter, 1 cm length) in 0.1M LiOH at 60 mA/cm^2 for two days and then increasing the current density for D_2O electrolysis to 600 mA/cm^2 for four days, continuously recording the heat generation rate;
2. Control Experiment - Recording of heat generation rates during electrolysis of D_2O in 0.1M LiOD on a Pt cathode (wire with same dimensions as in Experiment 1).

3. Test Experiment - similar to Experiment 1, but conducted in 0.1M LiOD. In this equipment, the heat generation rates were also recorded when the current density was increased from 0.6 A/cm^2 to 1.0 A/cm^2 and then decreased to 0.3 A/cm^2.

The results of these experiments may be summarized as follows:

1. Excess heat generation rates were observed only in the test experiment (Experiment #3) and not in the control experiments (Experiments #1 and #2).

2. The rate of excess heat generation was 19 W/ml of Pd, close to the value (26 W/ml of Pd) reported by Fleischmann and Pons. The observed heat generation rate showed no increase when the current density for electrolysis was increased from 0.6 to 1 A/cm^2 but decreased to 14 W/ml of Pd when the current density was lowered to 0.3 A/cm^2.

3. The results of the two control experiments confirm that the rates of recombination of H_2 or D_2 with O_2 are negligible and cannot account for the excess heat generation rate in the test experiment.

NEUTRON EMISSION AND THE TRITIUM CONTENT ASSOCIATED WITH DEUTERIUM LOADED PALLADIUM AND TRITIUM METALS*

K. L. Wolf, N. Packham, J. Shoemaker, F. Cheng and D. Lawson
Cyclotron Institute and the Department of Chemistry
Texas A&M University, College Station, TX 77843-3366

An experimental investigation has been conducted on samples of Pd and Ti which were loaded with deuterium through the electrolysis of D_2O and by absorption of D_2 gas. In approximately 200 experiments on 25 samples, statistically significant evidence for neutron emission was obtained in two separate experiments from one Pd-Ni electrolysis cell. Observed rates of 3-4 times the background rate of 0.8 neutrons/min (0.4-2.5 MeV) correspond to a 2.5 MeV neutron source strength of 50 neutrons/min over a period of 1-2 hours.

A 3" x 5" NE213 liquid scintillator coupled to a 5"-diameter RCA 8854 phototube was used for an overall efficiency of 5% for 2.5 MeV neutrons. Pulse shape discrimination (PSD) was used for n/γ discrimination. Cosmic ray rejection was provided by the PSD and by 2' x 4' x 1/4" plastic scintillator paddles. Antennas and the PSD were used for external noise rejection. The neutron detector was shielded from the heat produced by electrolytic cells and the temperature was monitored. Data were acquired with a CAMAC-based LeCroy 2280 system interfaced to an 80386 computer.

The presence of 5×10^{12} tritium atoms in the solution of the electrolysis cell was determined several days after the neutron production runs. Tritium detection was accomplished with a pair of low-noise EMI 9954 phototubes coupled to a 1 cm x 1 cm x 3 cm cell. Neutralized samples were mixed with a water soluble liquid scintillator for an efficiency of 30%, in coincidence mode. Energy spectra were compared to tritium standards for the efficiency and for identification through slope and end point determinations. Tritium content of the cell before neutron production is not known.

*This work supported by the U. S. Department of Energy under Grants DE-FG05-86ER40256 and DE-FG05-88ER40437 and by The Robert A. Welch Foundation.

Electrochemical "Cold Nuclear Fusion" Attempts at IPP

G. A. Wurden*, H. S. Bosch, J. Gernhardt, G. Janeschitz, F. Karger, J. Perchermeier

Max Planck Institut für Plasma Physik
8046 Garching, Federal Republic of Germany

Abstract

Following the report of Pons and Fleischmann, we (The Bavarian Bubble Bottle Team) have attempted to reproduce their claims of cold nuclear fusion, and failed. We note that our measurements would not be able to detect neutrons at the level of Jones *et al.* Three experiments were conducted without any signs of neutrons, tritium or gammas above backgrounds, and within $\pm 5\%$ accuracy calorimetry, no excess heating. Intrinsic tritium, differing from each D_2O bottle tested, was however observed.

The third, and most significant attempt used a 22 gram, 10 cm^2, cast (vacuum melted by an e-beam) palladium piece, which was electrolytically loaded with deuterium (99.75% purity D_2O, 0.11 M LiD, Pt mesh anode) at current densities of 200-250 mA/cm^2 for a period of 21 days. Current, voltage, water bath (well-stirred) and air temperature were monitored continuously with a strip chart recorder. The fully covered 170 ml central cell did not partition the electrolysis products, all calorimetry was done in steady state, (bath time constant 100 minutes), and air flow across the 1 liter water bath was kept constant. No isolation Dewar was used. Measurements of the actual temperature(s) directly in the center cell showed strong thermal gradients ($3 - 4°C$), so calorimetric measurements are only relevant for the well-stirred water bath/air temperatures (typically 45 and 26°C, respectively). An absolute resolution of better than 200 mW, out of 20 Watts typical input power, was obtained. The equilibrium temperature rise of the water bath was strictly linear with input power, calculated from $P_{in} = I * (V - 1.54v)$. A Kapton encapsulated 40 Ohm strip resistor was used in the water bath for reference ohmic input measurements. Fast reductions in current density, after waiting for a new thermal equilibrium, yielded nothing unusual. A BF_3 thermal neutron counter, (calibrated efficiency of 1 count/370 neutrons from the same location as the cell, backgrounds of 0.05 counts/sec, with 12 cm polyethylene moderator and a Cd shield), as well as a moderated Li^6I neutron detector, a large high-resolution, high efficiency (170 cm^3) GeLi gamma detector, a 2" NaI detector, and a proportional counter were used to look for radiation. Gamma backgrounds from K^{40}, Bi^{214} and Tl^{208} (Thorium decay in concrete), were easily seen in pulse height spectra. Backgrounds at our second floor location were 120 mrem/year gammas, and 10 mrem/year thermal neutrons, as measured by a Berthold LB1026 Radiation Monitoring system. No special shielding precautions against cosmic rays were used. A 4 Megawatt swimming pool nuclear reactor, 600 meters away from our building, was one of our additional background considerations! Tritium was measured in the electrolyte, D_2O samples, and H_2O (both with and without the LiD solute). A model 2260XL Tri-Carb Liquid Scintillation Analyzer by Canberra-Packard was used, with the old ($\geq$ 15 years) Merck heavy water yielding 210 dpm/ml from one vial, and 9.9 dpm/ml from another used for refilling. By contrast the LiD dissolved in pure H_2O (unneutralized) gave 6.6 dpm/ml. The cell was replenished with D_2O at a rate averaging 16 ml/day. The electrolyte after 19 days of operation measured 150 dpm/ml. In comparison, the D_2O from another bottle (with same Merck #, and purchased at the same time!) used in our first 14 hour experiment had 750 dpm/ml. Pulse height analysis suggests that true Tritium decay signals are present, and chemical fluorescence in the "cocktail" was not important (although measurable). Tritium can reasonably be explained from that originally present in the various D_2O flasks.

The experiment was terminated on April 28, by throwing the loaded palladium sample directly into liquid Nitrogen, immediately next to the bare BF_3 counter (backed by 25 cm of moderator), in order to attempt one of the Italian ENEA neutron production variants. No neutrons (sensitivity of 5 n/sec equivalent source strength) above backgrounds were seen, while counting for one hour, and also none while the piece warmed to room temperature over the next hour. Postmortem analysis of the darkened, hardened Pd piece showed large crystal grains (up to 2mm×2mm), and continuing evolution of gas bubbles at the grain boundaries even four days after the experiment was ended.

Measurements of Neutron and Gamma Ray Emission Rates and Calorimetry in Electrochemical Cells Having Pd Cathodes.

Massachusetts Institute of Technology

Department of Chemistry	D. Albagli, V.Cammarata, R. Crooks, M. Schloh, and M.S. Wrighton.
Plasma Fusion Center	X. Chen, C. Fiore, M. Gaudreau, D. Gwinn, P. Linsay, S.C. Luckhardt, R. Parker, R. Petrasso, K. Wenzel.
Departments of Nuclear Engineering and Materials Science and Engineering	R. Ballinger, I. Hwang.

Results of experiments intended to reproduce the excess heat and neutron emission from electrochemical cells[1] are presented. Radiation emission and power balance measurements were carried out on a set of electrochemical cells consisting of Pd cathodes, Pt anodes, and D_2O/LiOD or H_2O/LiOH electrolytes. The first phase of this experiment was aimed at determining gross excess heating effects (> 30% of applied power, calorimetry based on observation of temperature fluctuations for constant power input), or unusual neutron or X-ray emission, from cells with 6.4 mm diameter Pd rods operated for >45 days. The second phase of the experiment featured improved accuracy and data aquisition in experiments with 1 and 3 mm diameter Pd rods. Results of calorimetry (power balance measured in a constant temperature calorimeter), controlled to ± 15 mW, and calibrated neutron and X-ray measurements will be presented. In addition, we have measured ^{3}T levels in all cell electrolyte solutions before and after electrolysis, and we have analyzed for ^{4}He in effluent gas from cells containing 1 mm diameter Pd cathodes. We anticipate presentation of results regarding the presence of ^{4}He which may be present (trapped) within the Pd lattice.

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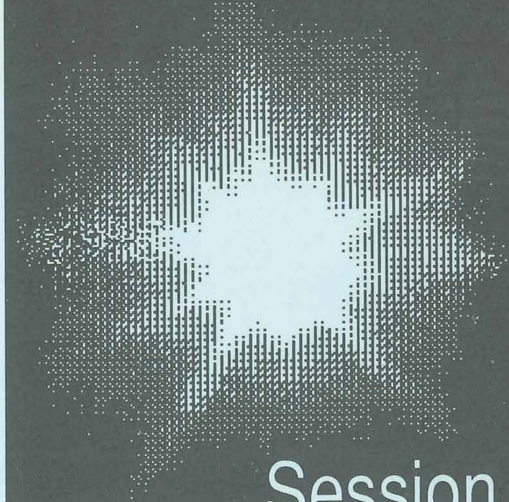
1. Fleischmann, M.; Pons, S.; Hawkins, M. *J. Electroanal. Chem.* **1989**, 261, 301.

IN SEARCH OF NUCLEAR FUSION IN ELECTROLYTIC CELLS AND METAL/GAS SYSTEMS. D.R. McCracken, J. Paquette, R.E. Johnson, N.A. Briden, W.G. Cross, A. Arjona, A.M. Lone, D.C. Tennant and W.J.L. Buyers, Chalk River Nuclear Laboratories, Atomic Energy of Canada Limited, Chalk River, Ont., Canada K0J 1J0, and K.W. Chambers, A.K. McIlvain, E.M. Attas and R. Dutton, Whiteshell Nuclear Research Establishment, Atomic Energy of Canada Limited, Pinawa, Man., Canada R0E 1L0. A variety of electrochemical cells having palladium cathodes in the form of wires, tubes, foils and rods have been used to electrolyse heavy water containing 0.1 mol.dm^{-3} LiOH, 0.1 mol.dm^{-3} LiOD or 0.50 mol.dm^{-3} D_3PO_4. Current densities of up to 140 mA.cm^{-2} were used. The mass of the palladium cathodes covered the range from 1 to 40 grams and the surface area varied from 8 to 140 cm^2. Neutron detection systems with low constant backgrounds were used to search for the presence of a neutron flux during electrolysis. These included moderated ^{3}He- and $^{10}BF_3$-based detectors. After running some of the cells for times up to 28 days no neutron flux above background could be detected. No enrichment of the electrolytes in tritium was evident after correction for evaporative losses. Chemical analysis of one of the cathodes after 25 days of near continuous electrolysis indicated that the average bulk composition was $PdD_{0.7}$ with the ratio of deuterium over palladium remaining constant to a depth of at least 20 μm. Experiments were also performed with the titanium metal/deuterium gas system. These consisted in exposing titanium metal to a deuterium gas pressure of 40 atm, lowering the temperature to -196°C, releasing the pressure and gradually warming the titanium to room temperature. No neutron flux above background was observed during these experiments.



Session B

Submitted to the Workshop on Cold Fusion Phenomena
May 23–25, 1989
Santa Fe, New Mexico

Search for Neutrons from Cold Fusion in Pd–D

R.S. Raghavan, L.C. Feldman, M.M. Broer, J.S. Kraus, A.C. James and D.W. Murphy

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We report on a search for neutrons from dd fusion in Pd rods loaded electrolytically with deuterium. Three Pd rods were used: 1) 0.125 dia. x 9 cm long, drawn and cold worked; 2) 0.125 dia. x 9 cm long, drawn and annealed; 3) 0.41 dia. x 8 cm long, cast, drawn and annealed. The rods were held in two electrolytic cells (D_2O (99.5% D)+ 0.1 M LiOD, current density 53 mA/cm^2) and placed before a 12.5 dia. x 12.5 cm NaI(Tl) detector with 5 cm of polyethylene (PE) moderator interposed. A pair of plastic scintillator plates above and below the NaI(Tl) vetoed cosmic muons. The apparatus was housed within 10 cm thick PE surrounded on the outside with Pb and borax. Fusion neutrons are moderated inside the PE housing, creating a slow neutron gas that can be detected by two γ–ray producing reaction signals: (1) n–capture by protons in the PE (2.224 MeV γ); (2) ^{23}Na and ^{127}I n–capture γ–rays in the range 3.5–7 MeV. The latter, produced inside the NaI(Tl), is the more sensitive signal. The background in this region, mostly due to cosmic rays, is far less than the background below 2.62 MeV, which is dominated by natural radioactivity. Therefore our results are insensitive to ambient natural radioactivity. From the overall n detection efficiency (measured with an Am–Be source immersed in D_2O(LiOD) at the counting position) and the observed background limit, we deduce that neutron production at the rate of ~ 0.1 n/sec in the cells can be detected. In a four–week measurement we observe <0.007 n/sec/g Pd, (0.4 cm dia. rod) compared to $2.6\mathrm{x}10^3$n/sec/g Pd, claimed in recent work[1] for a similar Pd rod. Our result implies $<2.2\mathrm{x}10^{-24}$ (ddn) fusions/dd pair/sec in our Pd electrode, as compared to $\sim 10^{-23}$ (ddn) fusions/dd pair/sec observed by Jones et al[2] in a Ti electrode.

1. M. Fleischmann and B.S. Pons, J. Electroanal. Chem. **261**, 301(1989).
2. S.E. Jones et al, Nature **338**, 737(1989).

Calorimetry, Neutron Flux, Gamma Flux, and Tritium Yield from Electrochemically Charged Palladium in D_2O

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We report the results of our work on cold fusion using palladium. We have used extremely sensitive neutron, gamma ray, and photo counters, and can place strict upper limits on the flux of expected nuclear products emitted from charged Pd cathodes. Liquid scintillation counting has been used to measure tritium production, which was found at background levels for extended periods of time. However, a subtle chemical interference that generates chemiluminescence has been shown to yield tritium signals and lead to overestimates of the fusion yield based on tritium production. We have also performed accurate, calibrated calorimetry, and have identified several serious errors that can make the measurements appear to show excess power production. When these common errors are eliminated, a correct energy balance is obtained. We have used cold-worked Pd, recast Pd, Pd thimbles, and Pd wires over a variety of pH values and for a variety of activation times. We will also discuss the calorimetry experiments performed by the Utah researchers, will explain their calculations to the physics community,and will clearly state the assumptions and corrections implicit in the Utah calculations.

SEARCH FOR FUSION IN DEUTERATED TRANSITION METALS: DYNAMICAL PRESSURES ABOVE 1 MEGABAR

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One can conceive a number of possible solid state or metallurgical mechanisms to produce enhanced fluctuation fusion rates in Deuterated Metals, such as Coulomb Screening, Crowdions, Dislocations, Crack Propagation, Shear Banding, Vacancy and Void Filling, Grain Interstices, Twinning, Tweeding and Surface Reconstruction, Dynamically Shrinking, through pressure, a transition metal lattice containing Deuterium probes all of these possible mechanisms simultaneously to some degree.

A Cylindrical Shock Experiment was performed on Deuterated Pd (0.3 gm) and Ti (0.1 gm) foils using a fully recoverable, high pressure, and well tested design. Four gm of Zn was also inserted in the experimental chamber as a post shot neutron radiochemical detector. The system was pressure tested and its free volume was measured. The system was then cleaned to remove gas contaminants, surface poisons or deuterium transfer inhibitors. The system was then back loaded with deuterium at room temperature initially at a pressure of 50 psi which dropped to a pressure of 30 psi of Deuterium gas. The observed uptake rates showed that both foils deuterated to about 0.7 D/M for Pd and about 0.7 for Ti. The sample container was removed from the loading system, maintaining gas tightness, and inserted into the high explosive configuration. The entire system was then subject to a Dynamical Shock Pressure of greater than 0.1 Tera Pascals. Prompt Neutron Detectors were placed behind protecting sandbags and Pb bricks in the close proximity of the experiment. Post Shot radiochemical analysis was also performed. The results showed that less than 10^4 neutrons were generated. No increased neutron flux over background was detected during the several microseconds of Dynamical Pressure on the deuterated foils. We conclude that whatever mechanisms are possible to enhance fusion rates in deuterated transition metals, they were not present at the detection level and pressures of this experiment.

Tests for "cold fusion" in the Pd-D_2 and Ti-D_2 systems at 350 MPa and 195-300K

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Experiments are in progress on the Pd-D_2 and Ti-D_2 systems at 350 MPa, 195-300K, to investigate the possibility that "cold fusion" occurs in high D/metal phases generated by pressurization with D_2 gas. Reactions between high-purity Pd or Ti and D_2 are being monitored using BF_3 neutron detectors and thermocouples. The neutron detector array has an efficiency of approximately 6%, as determined using a ^{252}Cf source. The pressure vessel and neutron detectors are immersed in a water bath thermostated at 300K. A type-K thermocouple in contact with the Pd or Ti sample is compared with a reference type-K thermocouple also housed in the vessel and located approximately 10 cm above the sample. The neutron flux, gas pressure, sample and reference thermocouples and bath temperature are continuously monitored at time intervals ranging from 6 seconds to 5 minutes.

Experiments completed to date in the Pd-D_2 system at 300K have shown no neutron flux significantly above background (9.5±0.5 counts/min.), and no sustained heat production has been detected.

Research sponsored by the Division of Engineering and Geosciences, Office of Basic Energy Sciences, U.S. Dept. of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

Measurements of Heat, Neutron and γ Flux Induced by μ Stopped in Deuterium Saturated Targets

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Abstract. We use small scintillation hodoscopes to define a pencil-size 80 MeV/c μ beam at BNL to stop negatively charged μ's inside Pd and Ti targets saturated with deuterium/hydrogen. Heat, neutron and γ flux produced from the targets as functions of the number of stopped muons are measured with calorimeters, BF_3/He_3 counters and NaI crystals respectively. The relative rates with/without stopping muons are measured using cast thin Pd rods in an ongoing electrochemical cell similar to that used by Pons and Fleishmann. The absolute rates are measured in targets made of thin foils. The background is calibrated both with targets in the beam but without deuterium/hydrogen and with targets saturated with deuterium but without muons stopped in them. We also search for any excess helium produced inside the target material. The results are compared with theories which claim cold fusion is induced by cosmic ray muons.

Abstract: 1) ELECTROCHEMICAL EXPERIMENTS IN COLD NUCLEAR FUSION, by J.F. Ziegler, T.H. Zabel, J.J. Cuomo, V.A. Brusic, G.S. Gargill III, E.J. O'Sullivan and A.D. Marwick, IBM Research Division, Thomas J. Watson Research Center, Yorktown Heights, NY 10598 USA. Recently, two scientific papers have reported positive detection of nuclear radiation from similar electro-chemical cells operating with deuterated water. Fleischmann and Pons have observed gamma rays at 2.2 MeV at a rate of about 4000/cc-s, and if the heat they observe is due to unobserved nuclear fusions, they have a fusion rate of about 10**12 fusions/cc-s (the subscript "cc" refers to the volume of Pd cathode used). In an independent work, Jones et al. have reported detecting 2.4 MeV neutrons at a rate of 0.7 neutrons/cc-s from an electrolytic cell.

We have experimented with similar electrolytic cells and have looked for energetic charged particles which are characteristic of nuclear fusion reactions. We report on six variations of cell, with an upper limit of 0.005 detected particles/cc-s. Within background statistics, we observe zero nuclear fusions. (Submitted to Physical Review Letters: 18 April, 1989)

2) Experimental reports of cold nuclear fusion continue to raise questions, e.g. in regard to details of stirring during calibration of the cells in which temperature rise is used to infer heat generation. Other possible problems include the assumption that power input is the product of time averages of voltage and current applied to the cell, whereas it is the time average of the instantaneous product. Monitoring the reaction cells for electromagnetic signals would help to determine whether "arcs and sparks" play a role in the generation of the nuclear particles observed in some experiments. Comments along these lines, updated to reflect experiments as of the time of presentation, may help in evaluation and to focus further experimental work.

Nuclear Reactions and Screened-Coulomb Fusion Rates

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We discuss properties of nuclear reactions (branching ratios, reaction constants, etc.) between hydrogen isotopes from the standpoint of recent R-matrix calculations. These calculations predict, for example, quite different branching ratios for the d+d reactions when they are initiated by S-waves than when they are initiated by P-waves. We will also give a more speculative discussion of the constraints on possible non-radiative electromagnetic transitions that could occur for the d-d and p-d reactions in the metal lattice.

When R-matrix theory is used to include nuclear effects at small distances in the calculation of fusion rates, the rate expression exhibits a more complex interplay of the short-ranged (nuclear) and long-ranged (screened Coulomb) forces than does the familiar separable form,

$$\lambda = A_0 |\Psi(r=0)|^2 ,$$

to which the R-matrix expression reduces if the appropriate approximations are made. Using the latest nuclear R-matrix information for the d+d and d+t reactions in this more correct formulation, we have calculated rates for a variety of screened Coulomb potentials. The fusion rate calculations are presented as a function of the screening radius at fixed relative energy, and as a function of relative energy at fixed screening radius. They are compared with calculations made using the standard expression above.

MOLECULAR DYNAMICS SIMULATION OF $PD_{1.1}$: HOW CLOSE CAN DEUTERONS GET?

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Crucial to whether cold fusion can occur in Pd or similar metals is how close deuterons can get to one another in the hydride lattice, particularly if the concentration is above stoichiometry and/or there is large thermal agitation. To investigate these questions a molecular dynamics (MD) simulation has been done of $PdD_{1.1}$ and the distribution of D-D distances examined.

Pd-D potentials were used similar to those in previous MD simulations of hydrogen diffusion. They were modified slightly to allow investigation of cases both where the tetrahedral (t) site was stable and unstable. The screening length was taken as $a_0/2$ (a_0 = Bohr radius) so as to be highly optimistic about a weakened repulsion allowing for close D-D distances. Simulations were done at temperatures of 300 K and 1300 K.

In no case were distances shorter than 0.7 Å found. Thus no evidence was found for D-D separations significantly less than in molecular D_2 (0.74 Å). The fact that a fair number of distances less than 1.5 Å, considerably shorter than the equilibrium 2.8 Å below stoichiometry, are seen may, however, have implications for other aspects of hydrogen in metals.

This work was supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

Conditions Leading to the Production of Cold Fusion Neutrons

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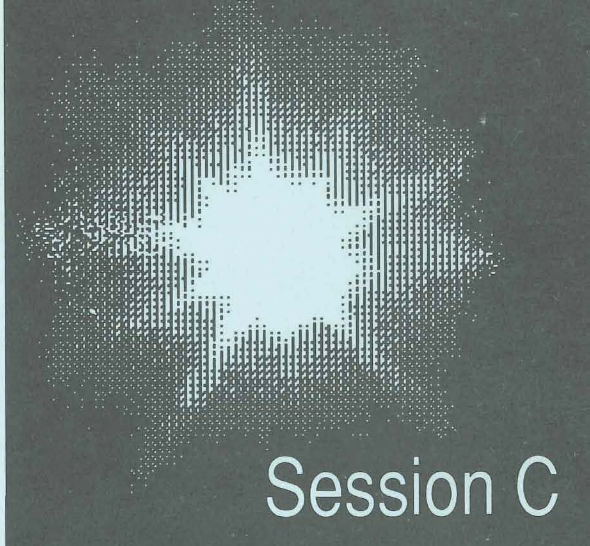
We have examined the conditions that must be attained within the metallic lattice in order to achieve $d + d \rightarrow {}^3\mathrm{He}+n$ thermonuclear fusion rates as observed by Jones *et al*, supposing that the so-called 'cold' fusion is occurring in small pockets of deuterium under plasma conditions. We establish i) the relevant time scales governing the plasma formation process, ii) the influence the conduction band electrons have on the fusion rate, and iii) the temperatures, densities and plasma lifetimes required to explain the reported neutron rates. The particular mechanism we are considering as being responsible for the formation of pockets of plasma is the catastrophic collapse of microscopic cavities between the metallic crystals, caused by the sudden expansion of crystals under stress. This process may lead to the formation of high density and temperature plasmas for brief periods of time. We note that the presence of the metal's conduction band electrons plays a significant role, firstly by screening the $d-d$ interaction and thereby reducing the temperature required for fusion, and secondly by absorbing the electronic component of the produced $d^+ + e^-$ plasma. The work is still in progress and at this time it is not established that the proposed model is a viable mechanism for neutron production. However, one can propose several experimental procedures whereby the creation of plasma pockets by the above mechanism may be tested. These include: i) the correlation of neutrons bursts with the application of mechanical stress or ultrasound to the material, and to the presence of micro-quakes which may be detected within the sample; ii) by initially preparing the metal sample in different ways so as to increase the amount of internal stress, such as by casting and cooling the metal very rapidly or by tempering; and iii) by combining the hydride with impurities that have different thermal expansion coefficients or which expand differently under hydridization. The plasma conditions that may exist could be probed by comparing different fusion reaction rates such as $p + d \rightarrow {}^3\mathrm{He}+\gamma$, $d + d \rightarrow {}^3\mathrm{He}+n$ and $d + t \rightarrow {}^4\mathrm{He}+n$.



Session C

COLD NUCLEAR FUSION IN CONDENSED MATTER: RECENT RESULTS AND OPEN QUESTIONS

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We have observed clear signatures for neutron emission during deuteron infusion into metals, implying the occurrence at low rates of nuclear fusion in condensed matter near room temperature. The cold fusion phenomenon has been demonstrated in collaborative experiments at Brigham Young University <1>, at the Gran Sasso Laboratory in Italy, and at the Los Alamos National Laboratory. We have shown that cold fusion can be induced in metals using both electrochemical and variational temperature/pressure means to generate non-equilibrium conditions <1>. Observed average neutron emission rates are approximately 0.04-0.4 n/s.

Current efforts focus on trying to understand and control the cold fusion phenomenon. In particular, we wish to understand the correlation of fusion yields with parameters such as hydrogen/metal ion ratio, pressure (induced, for example, by electric fields or gas pressure or mechanical pressure), temperature variations, hydride phase changes, and surface conditions (e.g., a palladium coating on titanium). We want to know if the fusion arises due to confinement of the deuterons in the lattice (piezonuclear fusion), or rather from 'microscopic hot fusion' accompanying strong electric fields at propagating cracks in the hydride. The latter interpretation would imply neutron emission in bursts.<2> Our experiments show clear evidence for emission of neutrons in bursts of less than 200 μs, although random (continuous) neutron emissions were also observed. Experiments now underway to compare the d-d, p-d, and d-t fusion rates will be important to an accurate description of the new phenomenon.

We should also consider the implications of this discovery. Although energy applications now appear extremely unlikely, cold fusion at enhanced rates could serve as a useful source of monoenergetic neutrons. Certainly, condensed-matter fusion provides a novel probe of extreme conditions in metal-hydrogen systems. Careful scrutiny of the effect could also increase our understanding of heat and helium-3 generation in the earth and other planets, and even in cooler regions of the stars.<1> The discovery of cold fusion may significantly impact our view of nature.

<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," **Nature**, 338: 737-740 (April 27, 1989).

<2> J. S. Cohen and J. D. Davies, "The cold fusion family," **Nature** 338: 705-707 (April 27, 1989).

EXPERIMENTAL EVIDENCE FOR COLD NUCLEAR FUSION IN A MEASUREMENT UNDER THE GRAN SASSO MASSIF

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We have observed the emission of 2.45 MeV neutrons following the electrolytic infusion of deuterons into titanium electrodes in a replication of experiments performed at Brigham Young University.<1> The present results were obtained using neutron-gamma discriminating proton-recoil detectors at the Gran Sasso Laboratory. The observed neutron emission rate is comparable to that reported by Jones and collaborators. The observation of cold nuclear fusion under the Gran Sasso Massif where cosmic-ray intensities are ~10^{-6} of sea-level values rules out the possibility that the observed neutron signal could be due to cosmic-ray muons or to cosmic-ray-induced neutrons <2>.

<1> S. E. Jones et al., "Observation of cold nuclear fusion in condensed matter," **Nature** 338: 737-740 (April 27, 1989).

<2> J. M. Carpenter; A. J. McCevoy and C. T. D. O'Sullivan, in "Cold fusion: what's going on?" **Nature** 338: 711-712 (April 27, 1989).

THE MEASUREMENT OF NEUTRON EMISSION FROM Ti PLUS D_2 GAS

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We have measured neutron emissions from cylinders of pressurized D_2 gas mixed with various forms of Ti metal chips and sponge. For some of the cases, the Ti was coated with a surface layer of Pd. The gas pressure ranged from 20 atm to 50 atm, and the Ti loadings ranged from 30 g to 200 g.

The neutrons were measured using a high efficiency (34%) cavity-type detector containing 18 ^3He tubes. Random neutron emissions were observed as well as time-correlated neutron bursts. The time spread in an individual burst was less than 200 μs.

The neutron emission was observed after the cylinder had cooled in liquid nitrogen temperature and was warming to room temperature. The bursts occurred about 40 minutes into the warm-up phase, and the random emission occurred for at least 12 hours after the sample reached room temperature. This cycle could only be repeated two or three times before neutron emission ceased.

The neutron emission rates were very low and the 12-hour random emission rate was 0.05-0.2 n/s. However, this yield was still 11σ above the background. The instantaneous neutron bursts were more dramatic with yields several orders of magnitude above the coincidence background rates.

NEUTRON EMISSION FROM A TITANIUM-DEUTERIUM SYSTEM

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UPPER LIMITS ON EMISSION RATES OF NEUTRONS AND GAMMA-RAYS FROM "COLD FUSION" IN DEUTERIDED METALS[*]

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ABSTRACT

A search for neutrons and gamma-rays emitted in "cold fusion" in electrolytically deuterided metals was carried out with a very low background and a sensitive neutron detection system, composed of an array of six liquid-scintillator neutron counters operating in coincidence, with total efficiency of ~1%. Pulse shape, pulse height and time of flight were measured for scattered neutrons. Gamma-rays were detected in two large (12.5 cm) NaI(Tl) detectors, with total efficiency of 0.1% at 5.5 MeV. The detection system was shielded from background radiation and two large area cosmic-ray veto counters were utilized. Up to four electrochemical cells, similar to the ones used by Fleischmann, Pons and Hawkins (FPH) and by Jones et al., ran concurrently, with Pd or cold worked Ti rods as cathodes. The Pd electrodes were cold worked or annealed in vacuum or argon, one electrode was predeuterided and various surface treatments were carried out. The metals were electrochemically charged with deuterium in heavy water (97.5% or 99.8% D_2O) electrolytes containing LiOD or a variety of salts. Ti alloy powder deuterided at room temperature and high pressure was also used for comparison. No statistically significant deviation from the background was observed in either gamma-ray or neutron detectors, over three weeks. Using our neutron detector system we estimate (with 98% confidence) the rate of "cold fusion" of d + d in our Pd and Ti samples to be smaller than the order of 10^{-25} fusions/atom pair/sec (3σ limit), and the gamma ray data yield for (the faster) p + d fusion rate, a limit of the order of 10^{-22} fusions/atom pair/sec (3σ limit). The estimated neutron flux in our experiment is a factor of 50-100 smaller than that reported by Jones et al. and some million times smaller than that reported by FPH. We suggest that the FPH quoted neutron flux is in error, and the rate of vetoed cosmic ray induced neutron events, in our data, suggests the observation of Jones et al. to be cosmic muon induced events. An attempt to initiate "cold fusion" with 5 MeV alpha particles produced no measurable effect.

[*] Supported in part by U.S.D.O.E. contracts Numbers: DE-AC02-76ER03074, DE-AC02-76CH00016.

LACK OF NEUTRON AND GAMMA RADIATION FROM PPPL's COLD FUSION EXPERIMENTS†

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We have tried to reproduce the various 'cold fusion' experiments(1 ,2) along with some variations to their basic schemes. To date, we have not seen evidence from any of our experiments for the production of either neutrons or gamma rays at rates above the background. Experiments performed include: (i) electrolysis in a pure D_2O cell with 1 molar LiOD (or LiOH) solution and various palladium cathodes at current densities up to 0.6 amperes/cm^2; (ii) electrolysis in a 50-50% D_2O-H_2O cell with a graded drawn Pd wire (or cast Pd sphere) cathode at current density up to 0.5 amperes/cm^2; (iii) thermal and pressure cycling of various high-pressure D_2 gas-loaded Ti turnings, and Ti powders, a Nb bar, alumina, quartz, and feldspar mixtures, etc..

For all the experiments, neutrons were measured with BF_3 proportional counters and gamma rays with NaI scintillation detectors, but at different times and with separate test stations. The neutron monitoring station was shielded with a polyethylene moderator and cadmium absorber, and the background count rate was found to be highly variable, ranging from 5 counts/hr to 30 counts/hr. The neutron detection efficiency was determined with a ^{252}Cf source to be 1% for experiments (i) and (ii) and 0.1% , 0.3% , or 1% for experiment (iii), depending on configuration. The gamma-ray station employed a NaI scintillator-photomultiplier closely coupled to the electrolysis cell. The detector was surrounded by a cylindrical annulus of NaI fitted with 6 photomultipliers. The central and surrounding detectors were operated in anti-coincidence mode to minimize spurious signals from external sources. The experiment was surrounded by lead shielding to further reduce background; the background rate was 5 - 15 counts/hr in a 1- MeV wide window around the 5.5 MeV region of interest. The gamma detector energy calibration was determined with ^{60}Co and ^{137}Ce sources. We thus claim that our neutron counting apparatus can continuously resolve a neutron source strength of 1 neutron/sec and our gamma counting apparatus is capable of resolving a gamma source strength of 1 photon/sec. However, our apparatus could not detect neutrons as low as the level of Jones et al(3).

We have considered the possible proton- and deuteron-induced nuclear reactions with the various isotopes present in the electrolysis apparatus. We note that there are no bound excited states in ^{4}He, and only 3 unbound excited states lie below the d + d reaction threshold. The width of the lowest lying excited state (at 19.8 MeV) is 0.27 MeV, the higher excited states are broader and overlap strongly, and thus, one would expect the nearly prompt (10^{-20} sec) decay by particle emission from the compound ^{4}He nuclei rather than an electromagnetic mode of decay (see, for example Ref. 4). Therefore, in our theoretical efforts, only two mechanisms for 'cold fusion' are considered: (i) tunneling through coulomb barrier by 'cold' deuterons, and (ii) cold target bombardment by deuterons accelerated in bursts(5). The fusion rates for tunneling in p-D, D-D, and D-T molecules have been computed. The dependence of fusion rates on electron mass and temperature will be presented. This suggests that if the experiments of Ref. 1, 2, 3, and 5 were repeated with mixtures of hydrides and deuterides, the relative importance of quantum-mechanical tunneling vs. simple cold target bombardment would be determined.

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† This work is supported by the U.S. DoE contract No. DE-AC02-76-CHO-3073.

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2. DeNinno, A. et al., submitted to Europhysics Letters.
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5. Klyuev, V.A., et al., Sov. Tech. Phys. Lett. 12, 551 (1986).

AN ATTEMPT TO MEASURE CHARACTERISTIC X-RAYS FROM COLD FUSION

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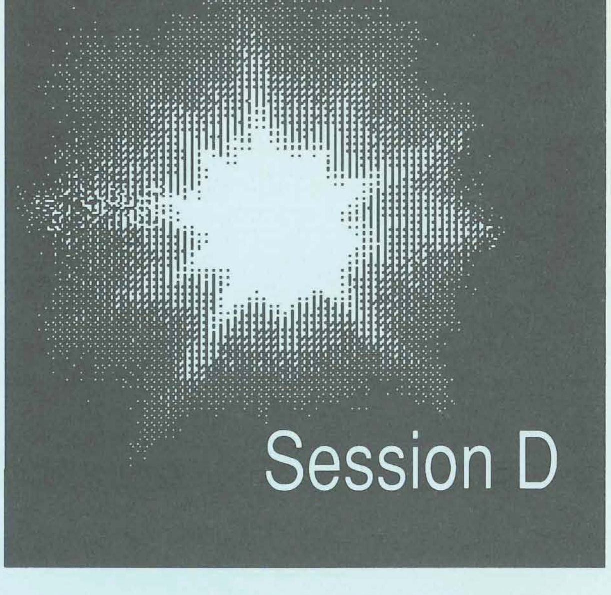
We have carried out tests using an electrolytic cell modeled after the Pons-Fleischmann descriptions, but with several modifications to allow the detection of characteristic X-rays emitted from the palladium electrode. In virtually any fusion reaction that could be postulated as taking place within the electrode, the energetic charged particles formed in the reaction would inevitably excite 21 keV characteristic K X-ray from palladium. If the structures and water of the cell do not absorb these X-rays before they emerge, then an external detector can have nearly 100% intrinsic efficiency for their detection.

A 1.5 by 1.5 cm palladium foil of 0.5 mm thickness was located within several millimeters of a thin nylon window fitted into the side of the glass cell. Two additional platinum electrodes were mounted at either side of the cell, and 0.1 M LiOD electrolyte in heavy water filled its internal volume. An electrolytic current ranging from 7 to 48 mA was sustained over a period of 7 days. The palladium electrode was observed to distort somewhat over this period, consistent with the hypothesis that substantial deuterium loading of the metal took place.

A germanium detector with thin endwindow was placed within several millimeters of the cell window outer surface throughout the experiment. Background data were obtained by inserting a 0.2 mm thick copper disk in front of the detector, of sufficient size to shadow the palladium sample. In separate measurements, a radioisotope source of X-rays was used to calibrate the detector energy scale and to verify the transmission properties of the cell components.

Over the period of time during which current was flowing in the cell, and for one day thereafter, no statistically significant differences were observed in data taken with and without the copper disk in place. We therefore conclude that no measurable characteristic X-rays were generated in the palladium over the period of the experiment.



Session D

Calorimetric and Thermodynamic Analysis of Palladium-Deuterium Electrochemical Cells*

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A controversy exists concerning the analysis of the heat observed from palladium-deuterium electrochemical cells. This is partially due to the fact that calorimetry can only measure the enthalpy (heat) of the reaction; whereas, the energy supplied to the Pd-D electrochemical cells reflects a free energy of the reactions occurring within the cell. The fundamental interrelationships among the diverse concepts of 1) calorimetrically measured heat, 2) the cell potential, 3) the thermoneutral potential, 4) electrolytic and galvanic electrochemical reactions, 5) the endothermic cooling effect of the heavy water electrolysis, 6) the energy returned from any subsequent gas recombination, and 7) the internal pressure, fugacity, and thermodynamic activity of deuterium in the palladium will be presented.

The experimental effort at Sandia National Laboratories includes the calibration of a unique calorimeter, which operates on the principle of accurate measurements of the vaporization rate of liquid freon which completely surrounds the Pd-D cell. Unlike other recent calorimeter experiments on the Pd-D system, this calorimeter does not depend on the measurement of temperature within the cell and, therefore, avoids the present objections of possible temperature gradients (due to poor mixing within the cell) causing the reported excess heats.

The freon vaporization calorimeter has been assembled and initial electrical calibrations show a measured power resolution of 0.1 watts. Measurement of cell temperature will also be performed to give an independent measure of cell heat output. We installed He^3 neutron detectors around the cell to allow one of the first simultaneous sensitive radiation with calorimetry experiments. We will report on results of this combined calorimetry/radiation experiment at the time of the workshop presentation.

The Possibility of Evaporation Dominating "Cold Fusion" Power Balance Calculations*

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The primary assertion of Profs. Fleischmann and Pons in their recent experiments with electrochemical loading of deuterium in palladium[1] is that more energy is produced than is consumed in the process. Their attribution of this excess energy to nuclear fusion is derived from a power balance calculation based ultimately on Newton's Law of Cooling which may not be directly applicable in their experimental situation. They use a submerged resistor to heat the electrolyte solution and assume a constant heat transfer coefficient which in turn is used to calculate the energy loss rate, $k_T\Delta T$, to the surrounding environment.[2] Since the sum of this calculated loss rate and the chemical potential increase from electrolysis is greater than the electrical power input, they require the additional energy source. However, total heat loss (especially from evacuated Dewar cells) may be dominated by evaporation of electrolyte which increases exponentially with temperature. In many everyday situations, evaporation is limited to small amounts by vapor diffusion rates. In this experiment, the bubbles of electrolyzed D_2O are saturated with water vapor and also serve to enhance convection of water vapor from the surface. Thus, during the calibration period at higher temperature, they may have overestimated the heat transfer coefficient applicable at the lower operating temperature. Even though the change in temperature for the calibration run described in ref. 2 was only 1.55 K, the corresponding water vapor partial pressure change, ΔP, which drives evaporation, is large. The key to the difficulty is the nonlinearity of the heat loss process with temperature variation, i.e., k_T is not constant. Other nonlinear chemical reactions involving heat loss from the cell could also contribute to the perceived energy balance discrepancy. If evaporation dominates, energy loss can vary as $k_p\Delta P$, where k_p is a constant. In this paper, calculations are presented to support the plausibility of this argument which negates the reason to postulate significant levels of fusion power.

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* This work supported by the U. S. Department of Energy under contract DE-AC04-76DP00789.

Abstract to be submitted to the Workshop on Cold Fusion Phenomena,
May 23-25, 1989, Santa Fe, New Mexico

CALORIMETRIC MEASUREMENTS ON ELECTROCHEMICAL CELLS WITH Pd-D AND Pd-H CATHODES

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Introduction

The purpose of these experiments was to verify the results provided by M. Fleischmann and S. Pons, University of Utah [1]; they were not designed to verify the results of S.E. Jones [2]. The experiments sought to determine the presence of "excess heat"; experiments will also be undertaken to determine the presence of neutrons.

Technical Approach

Two series of experiments have been performed: (1) differential comparison of temperature deviations between identical light- and heavy-water electrochemical cells and (2) calorimetric measurements of heavy-water cells under varying electrochemical conditions.

In the first series of experiments, the temperature difference of identically built and operated (current density and operational times) Pd-H/LiOH-saturated H_2O/Pt and Pd-D/LiOD-saturated D_2O/Pt cells was observed. We anticipated that both cells would operate at identical temperatures but that the D_2O cell would become much hotter after the onset of cold fusion. However, we found it difficult to provide identical conditions in both cells. At identical current density, the operating cell voltage of the D_2O cell (therefore, also the temperature) was higher. When the current density and the voltage were made identical, the H_2O cell became warmer (ΔT=0.8 K). We concluded that this type of experiment was too ambiguous and not suitable for evaluating the levels of heat and the special effects of deuterium now being reported.

In the second series of experiments, two Pd-D/LiOD-saturated D_2O/Pt cells in constant-heat-loss calorimeters were operated to detect "excess heat" evolution. Excess heat is defined in this report as a heat output from the cell that is higher than the heat equivalent of the electrical input [(cell voltage minus 1.53 V) multiplied by cell current]. The cathodes in both kinds of experiments were wrought palladium 5.0 cm in length and 6.3 mm in diameter. Under a series of well-defined electrochemical conditions (times and electrolyte additives) that were expected to increase the D/Pd ratio, we examined the various contributors of the electrical and heat inputs and outputs at various current densities (15-300 mA/cm^2). In addition, we calculated the mass and heat balances for the duration of the experiment to evaluate short- and long-range system transients. Thus far we have not found any excess heat within the sensitivity (0.13 W, 0.082 W/cm^3 of Pd or 0.013 W/cm^2 of Pd) and precision of the calorimeter. For now, the experiments are continuing. A detailed description of the experimental apparatus and of the analysis of the measured data will be presented.

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Acknowledgment

Work supported by the U.S. Department of Energy under contract W-31-109-Eng-38.

Electrochemical Calorimetric Studies on Water and Deuterium Oxide Electrolysis.

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This talk will focus on our preliminary results on calorimetric studies on water and deuterium oxide electrolysis using Pt or Pd cathodes with LiOH(D) and NaF as the supporting electrolytes. In some cases, sulfur was added as an intentional poisoning agent. The Pt or Pd rods were 1 to 1.5 mm in diameter. Radiation levels were monitored by neutron activation of copper or silver metal. These studies were prompted by a recent note on electrochemically induced nuclear fusion (1).

A deuterium oxide solution, containing NaF and the Pd cathode poisoned by sulfur was electrolyzed for 14 days. In terms of excess heat, the results appeared to be negative. Next, matched cells, with a Pd cathode in one and a Pt cathode in the other were tested for temperature differences in deuterium oxide containing 0.1M LiOD. After one week of electrolysis (100 mA/cm^2), no unexplained temperature differences between these cells were observed. However, this experiment is ongoing, and any future results will be given.

A comparison of the steady state heat evolution between water and deuterium oxide (LiOH(D) electrolyte, Pd cathode) indicated that the deuterium oxide cell was producing more heat than the water cell. The Newton cooling constants, 0.0538 J/s^{o}C (H2O cell) and 0.0541 J/s^{o}C (D2O cell) were determined by resistance heating in well stirred solutions. During the electrolysis (100 mA/cm^2), no temperature changes were noted as a function of the thermometer placement, and thus, the cells were not stirred mechanically. All trials resulted in an excess calculated heat, with the D2O always producing more excess than the water cells. For example, in one trial the excess heats were 0.201 and 0.223 J/s for the water and D2O cells, respectively. We attribute these observations, wholly or in part, to recombination of the gases (2). Further refinements on these cells are being made and the results will be shown and discussed.

Finally, remote monitoring of a scaled-up cell, in hopes of recording the Pd ignition event (1), is being planned. Progress towards this effort will be described.

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ABSTRACT

SEVEN CHEMICAL EXPLANATIONS OF THE FLEISCHMANN-PONS EFFECT

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Seven chemical explanations are stated and quantitatively analyzed. (a) The D_2O solution drops below the top of the electrode, and it pumps H out to an O contact at the Pd - gas interphase. (b) The same, but the situation described occurs inside the electrolyte with O_2 in bubble form from the anode, impelled sporadically against the cathode.

(c) $D_2 + O_2$ recombination in the gas phase.

(d) The $\alpha \rightarrow \beta$ transition is incomplete and continues for > 100 hours.

(e) The H/Pd ratio grows 0.7 - 1.25 over ~100 hours.

(f) Pd D_2 forms and dissociates sometimes explosively.

(g) Li alloys with Pd and this provides a heat of reaction.

The watts provided by these effects are compared with the heat reported from the Pd-D_2 system at high overpotential.

EVIDENCE AGAINST CONDENSED MATTER FUSION INDUCED BY COSMIC-RAY MUONS

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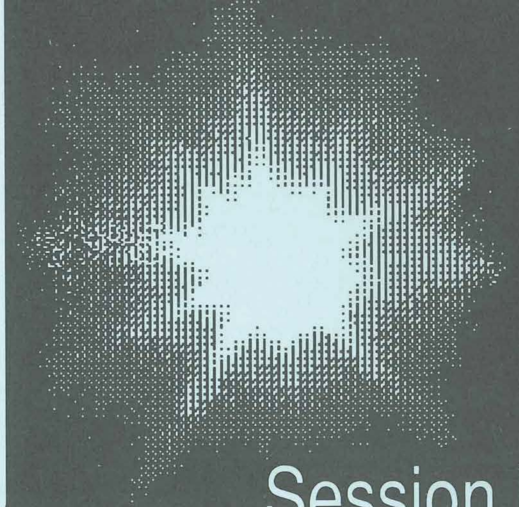
If has recently been proposed that the cosmic ray muons might catalyze d-d fusion in condensed matter[1], offering a possible origin for claims of observations of fusion neutrons from deuterated Pd or Ti. In order to test this hypothesis, we have studied the behavior of accelerator-produced negative muons in Pd(D).

The experiment was carried out at the pulsed muon facility of UT-MSL/KEK by measuring the following muon-induced envents ; a) timing of decay electrons to see the relative fraction of muons stopping in D versus Pd by a lifetime method; b) energy and timing of neutrons with n-γ discrimination to see fusion neutrons ; c) energy and timing of X-rays to see (μ^3He) events associated with $(dd\mu)$ fusion if it exists. All the experimental arrangements employed here were the same as those used for the recent successful experiments on a direct observation of alpha-sticking phenomena in liquid and high T_2 concentration D_2/T_2 mixtures by the X-ray method[2].

The Pd(D) samples used were a) a 5mm diameter Pd rod with 10 days D loading ; b) a 3mm thick Pd plate with 60% D loading; c) a 1mm thick Pd plate in D_2O with electrolysis in situ. As a control, we used Pd samples without D.

So far, no differences were observed between Pd and Pd(D) in all the above observables for these 3 systems, placing a limit on atomic capture ratio for D to Pd (below 5%) and on $(dd\mu)$ fusion rates in Pd(D) (below $0.1/\mu^-$). The obtained result provides evidence against the extraordinarily enhanced fusion rates assumed in the proposal[1].

/1/ N. W. Guinan et. al., UCRL Preprint 10081 (1989)
/2/ K. Nagamine et. al., to be published (1989)



Session E

PAC STUDIES OF ELECTROLYTICALLY CHARGED METAL CATHODES *[1]*

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Cold nuclear fusion reactions might occur at special, "active" sites in the cathode, such as in lattice vacancies. We have investigated hydrogen (H) interactions with vacancies in metals on an atomic scale, using perturbed γ-γ angular correlations (PAC) of ^{111}In probes.*[2,3]* Our approach has been to trap diffusing H atoms in pre-existing probe-vacancy complexes. H trapping is detected microscopically by changes in the hyperfine interactions signals. Binding enthalpies of ~0.5 eV and occupation numbers of H in the complexes have been deduced from changes of signal amplitudes during charging and annealing. Some results are as follows:
(1) Divacancy and trivacancy complexes in Ni*[2]* and Pt*[3]* are rapidly decorated by H atoms after charging for a few minutes at 20 mA/cm^2 in 0.1 M H_2SO_4.
(2) NiH can be formed by charging Ni at ~200 mA/cm^2, whereas it is only formed under gas pressures in excess of 6 kbar.
(3) Li was the only common cation in electrolytes used by Fleischmann and Pons and by Jones et al. Because its radius is small, Li may diffuse interstitially in the cathode, like H. Using a Pt cathode and 1.0 M LiOH electrolyte, the pH was observed to drop from 13.3 to 9.4 after 24 hours at ~20 mA/cm^2, demonstrating that most Li deposited onto and/or diffused into the electrode. Experiments are in progress to detect Li diffusion in the lattice by observation of new signals corresponding to Li-decorated vacancy complexes.

[1] Supported in part by NSF grant DMR 86-19688 (Metallurgy Program).

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INTERACTION OF DEUTERIUM WITH LATTICE DEFECTS IN PALLADIUM

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ABSTRACT

The interaction of ion-implanted deuterium (D) with lattice defects and He bubbles/voids in single crystals of palladium (Pd) was investigated by ion-beam-analysis techniques. Experimental data for the amount of D retained during linear-ramp annealing were analyzed using transport theory to obtain trap strengths. Small He bubbles/voids were found to trap D with a binding enthalpy of 0.31 eV relative to the solution site, whereas implantation damage trapped D with three different binding enthalpies, 0.31 eV, 0.23 eV, and 0.15 eV, attributed respectively to vacancy clusters, monovacancies with low D occupancy, and monovacancies with high D occupancy. Each Pd vacancy can accomodate up to six D atoms. The lattice location of D trapped to monovacancies is obtained by the channeling technique, following anneals at various temperatures. At low temperatures, T~25 K, D occupies the octahedral (O_h) interstitial site which is the solution site for D in fcc metals. At T~100 K, D becomes trapped by vacancies, and at 200 K, just before the depopulation from the vacancy is initiated, 60% of the D is at a near-tetrahedral site, in which the remaining 40% is deposited 0.3 Å from the O_h site towards the vacancy. The experimental results are compared with the theoretical prediction of the effective-medium theory.

SEARCH FOR COLD FUSION IN SUPERSTOICHIOMETRIC PALLADIUM DEUTERIDE USING ION IMPLANTATION

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Deuterium-deuterium distances in D-charged Pd are expected to be reduced for D-to-metal atom ratios above one, since excess D remains after filling of the octahedral interstitial solution sites. Such atom ratios are usually not achieved by electrochemical or gas-phase charging, but D ion-implantation at a temperature of 35 K was previously found to yield compositions up to D/Pd = 1.3. We have implanted similar high fluences of D into Pd at 40 K and an energy of 10 keV, and have used a solid-state detector to search for high-energy D and T particles from the D-D nuclear reaction. Copious charged particles of the appropriate energies were produced by the impinging D beam, thereby verifying the operation of the detection system and permitting the buildup of the D concentration to be monitored. After the beam was turned off, however, fusion events were not detected during about 9 hours of counting at 40 K. We estimate an upper bound on the reaction rate of 10^{-21} events/D/s. Similarly negative results were obtained for D-implanted Zr.

During warmup of D-implanted Pd, the D/Pd atom ratio was monitored by measuring the yields of energetic H and T induced by bombardment with 30-keV D. The D concentration decreased in distinct stages at 120 and 220 K. The first stage is attributed to rapid diffusion of the excess D in the superstoichiometric hydride, and its occurrence supports the existence of a D/Pd ratio above one; the second stage is then ascribed to D release by conventional diffusion in the normal hydride phase. Theoretical consideration of the respective diffusion processes yields relative rates consistent with the temperature separation of the two stages.

This work was supported by the U. S. Dept. of Energy under Contract. No. DE-AC04-76DP00789.

Tritium Enrichment in the Electrolysis of D_2O

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The tritium content of heavy water manufactured by the GS process (H_2S - H_2O dual temperature exchange) is calculated as a function of the tritium content of the feed to the heavy water plant. Fresh heavy water has a tritium activity of 68 dpm (cc D_2O)$^{-1}$(TU)$^{-1}$. The gross tritium enrichment into heavy water during electrolysis is calculated from the theory of relative enrichment[1] and the experimental data of Ostlund and Werner [2] as a function of the T/D separation factor. For separation factors in the range $1.6 < k_D/k_T < 2.2$, the overall enrichment increases from 1.4 to 5.1 as the fraction of water electrolyzed increases from 0.6 to 0.95. Implications with respect to cold fusion experiments will be discussed.

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Nuclear Fusion from Crack-Generated Particle Acceleration

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We propose a conventional interpretation for the neutron production in electrochemical ("cold" fusion) experiments(1,2). We suggest that electrostatic acceleration of deuterons results from internal cracks in the highly-stressed, deuterium-loaded metal lattices. After sufficient internal stresses have accumulated, cracks may propagate through the metal. The lattice surfaces, on either side of the crack, are left with unbalanced electrical charge. As the crack grows, the charged surfaces separate while maintaining constant charge, thereby increasing the voltage across the crack gap, as $V = 10^9 \eta d$ eV, here η is the number of imbalanced charges per square lattice constant (16 square angstroms for palladium), and d is the gap separation. With $\eta = 0.1$, and $d = 10^{-5}$ cm, $V = 10^3$ eV, or with $d = 10^{-4}$ cm, $V = 10^4$ eV. Stray deuterons falling across the gap may then acquire energy sufficient to produce conventional d-d nuclear reactions at rates comparable to those apparently observed in some cold fusion experiments (1,2). The surface charge must be maintained for at least the deuteron transit time across the gap, roughly a few picoseconds. A number of effects, near the tip, may allow for this relatively long relaxation time.

The electrostatic stored energy in the crack electrostatic fields is easily calculated to be about $E = 10^5 \eta^2 d/2$ joules/cm². If the cracks are created and then electrostatic energy is discharged from tens of square centimeters per second, then watts of electrical power may be released and appear as excess heat.

Finally, lattice fracture, in strongly shocked, lithium deuteride, has recently been proposed by Klyuev (3), et. al., as the mechanism responsible for their observed d-d neutron generation at low levels.

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Search for 0.8 MeV ^{3}He Nuclei Emitted from Pd and Ti Exposed to High Pressure D_2

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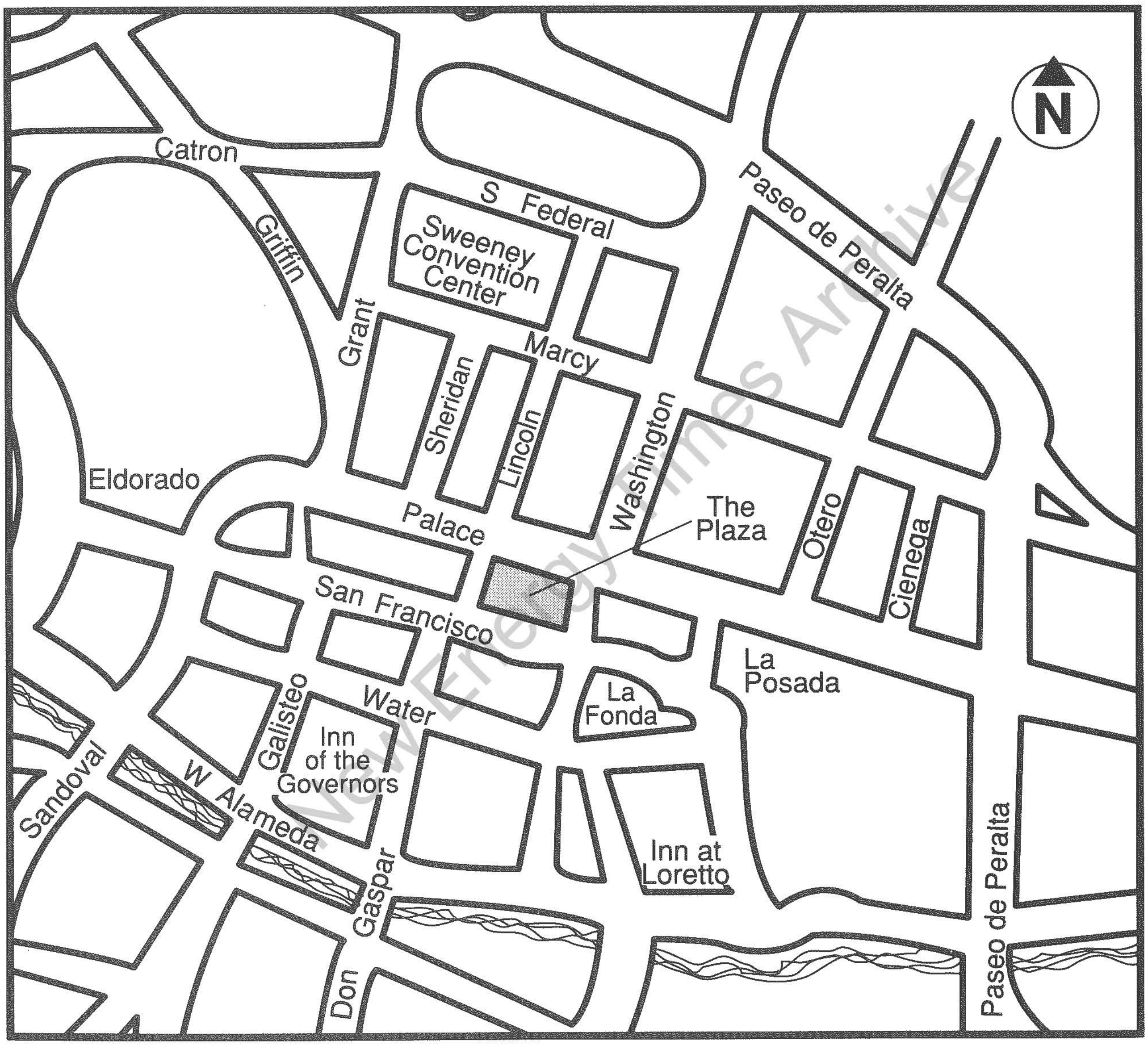
To look for evidence of cold fusion leading to n + ^{3}He, we have exposed track-recording plastic films in direct contact with Pd and Ti sheets inside a cell containing D_2 at pressures up to ~15 bars. A portion of each film not in contact with metal served to measure backgrounds due to alpha decay of radon and to cosmic ray-induced spallation of C and O in the plastic films. We have cycled between 77 K and 300 K and between 1 and 15 bars, and also reduced the pressure with a forepump as done at Frascati. For a Pd sample with atom fraction D/Pd = 0.5 (measured by weight gain) the track density due to ^{3}He ions emerging from the surface was <20 cm^{-2}; results for Pd loaded to D/Pd = 0.8 by electrolysis and for Ti loaded with D will be reported. The corresponding limit on the number of neutrons, ~4 x 10^4 per gm, is far lower than the numbers reported in the two Frascati experiments with Ti (~3 x 10^5 per gm and ~3 x 10^6 per gm) and in the Genoa experiment with Pd (~6 x 10^7 per gm). We calculate that lattice damage cannot explain the non-reproducibility of the Italian experiments.

Downtown Santa Fe



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ELECTROCHEMICAL EXPERIMENTS IN COLD NUCLEAR FUSION

air

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Recently, two scientific papers have reported positive detection of nuclear radiation from similar electro-chemical cells operating with deuterated water. Fleischmann and Pons have observed neutrons at about 2.5 MeV at a rate of about $4000/cm^3 - sec$, and if the heat they observe is due to unobserved nuclear fusions, they have a fusion rate of about 10^{12} $fusions/cm^3 - sec$ (the subscript "cm^3" refers to the volume of Pd cathode used). In an independent work, Jones et al. have reported detecting 2.4 MeV neutrons at a rate of 0.7 $neutrons/cm^3 - sec$ from an electrolytic cell.

We have experimented with similar electrolytic cells and have looked for energetic charged particles which are characteristic of nuclear fusion reactions. We report on six variations of the cell, with an upper limit of 0.005 detected particles/cm^3-sec. Within background statistics, we observe zero nuclear fusions.

Fusion2A on AL6.2

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Two recent papers have created wide-spread interest in Cold Nuclear Fusion (CNF) by reporting the detection of nuclear reaction products from similar electrolytic cells. Fleischmann and Pons (1) have reported the observation of excess gamma rays, neutrons and ^3H from a cell with an anode of Pt, a cathode of Pd and an electrolyte of heavy water, D_2O, with LiOD. Their gamma ray spectrum has a pronounced peak at 2.2 MeV, which they suggest may be from a n+p nuclear reaction (the electrolytic cell is surrounded by a H_2O moderator and neutrons from CNF d+d reactions may interact with the protons in the water). Further, they report massive and sustained heat generation -- of the order of $4MJ/cm^3$. This heat cannot be accounted for by chemical means, so the conclusion they reach is that the heat must be due to CNF processes of an unknown type. The heat produced was observed to scale with the Pd cathode volume, so the CNF is presumed to occur throughout the cathode metal.

Jones et al. (2) have reported the observation of neutrons during a similar electrolytic experiment, with an anode of Au, a cathode of Pd or Ti, and a complex electrolyte of various metallic salts (chosen to represent typical components of the Earth's crust) in heavy water, D_2O. Their neutron spectrometer shows a peak at about 2.5 MeV, exactly the energy of the neutron produced by a d+d nuclear reaction.

Both of the above experiments are difficult to reproduce in detail since there was minimal reporting of material analysis before or after the operation of the cells. No mention was made of contamination of the electrolyte from, for example, chemical erosion of the electrodes or of the glass cell walls. Neither group reported an analysis of the electrolyte or cathode after successful cell operation. Both groups have discussed an "incubation period" of charging the cathode, possibly to raise the deuterium concentration within the Pd cathode to the high levels found in β - Pd.

Both of these works reflect a long scientific interest in cold nuclear fusion which dates back to 1926 (3). A successful demonstration of CNF could have a profound effect on man's future.

Our approach has been based on the fact that all exothermic cold nuclear fusion combinations have one product in common: energetic charged particles. The above reports have looked at gamma rays, neutrons and excess ^3H -- all of which have large backgrounds in most laboratories. However, energetic charged particles have a background only from naturally occurring alpha particles and cosmic rays. Both of these can be reduced to levels of less than five detected particles per day, a level about 10^{-6} less than that usually reported for the detection of gamma rays or neutrons. Further, the detection efficiency of particle detectors, such as silicon surface barrier detectors (SSB detectors), is about 100% for all energetic incident charged particles in contrast to efficiencies of less than 10% for most gamma or neutron spectrometers.

The charged particles from d + d fusion reactions range from 1 to 3 MeV. We have constructed electrolytic cells with Pd cathodes which directly cover SSB detectors, see Figure 1. Ref. (1) has shown that CNF scales with the volume of the Pd cathode. Hence any fusions which occur close to the back surface of the cathode may produce particles which can be detected by the SSB detectors. Since one d + d nuclear reaction product is an energetic proton (3.02 MeV) which has a range in Pd of about 30 μm, then Pd cathodes thinner than 25 μm will allow most of these emitted in a backward direction to be detected.

Our cells have SSB detectors with a solid angle of about one π and a background of about 5 counts/day (for 1 - 3 MeV particles).

EXPERIMENTAL PROCEDURE : The electrolytic cells are shown in Figure 1. Each cell is made from 8 cm diameter cylindrical teflon with a hollow cylindrical well 5 cm in diameter by 8 cm deep. A 7cm^2 conical hole in the inner surface of the cell leads to a 2 cm^2 Pd cathode. A surface barrier detector faces against the back of the cathode.

The anode is made of Pt (99.9%), 2 cm wide by 4 cm long, with a thickness of .25 mm. Its distance from the cathode may be varied, but usually it is kept at a distance of 2 cm (as in Ref (2)). A thermocouple was attached to the top of the Pt anode to determine approximate electrolyte temperature without introducing possible contamination to the electrolyte.

The cathode is Pd (99.9%), with thicknesses ranging from from .025 - 0.5 mm. One problem with using Pd foils as a part of the cell wall (or figuratively as a cell window) is the possibility of hydrogen gas leaking out from the back surface of the cathode into the air. To prevent this leakage, dense Au films were sputter deposited on the back side of the Pd (the side away from the electrolyte). The Au was made to adhere firmly to the Pd by evaporating an intermediate layer of Cr, 200 Å, which acted as a glue. These Au films ranged from 1.7 - 6.5 μm in thickness (the effectiveness of these films is discussed later). These films were thin enough to let charged particles pass with modest energy loss (protons at 2 MeV lose 90 keV/μm).

The electrolytic cell holds about 150 cc of electrolyte. The top is closed except for seven 1mm holes to release gas pressure and to allow adjustment of the anode position, see Fig. 1. The electrolyte consisted of various amounts of H_2O (100 %) and D_2O (99.5%), with 0.1 molar LiOD as the electrolyte. The lithium hydroxide was made from Li metal (90% ^{6}Li and 10% ^{7}Li) reacted with D_2O. The pH of the electrolyte was measured as 12.4.

Various mixtures of H_2O and D_2O were tested as electrolytic solutions because conventional nuclear theory suggests that cold fusion reactions of d+p can have much greater cross-sections than d+d reactions. Since both Ref (1) and (2) did not use pure D_2O, it was possible that they were seeing products of d+p reactions instead of the d+d reactions they presumed. It was felt that a mixture of H_2O (10%) with D_2O (90%) would give comparable amounts of ^1H and ^2H within the Pd cathode metal on the basis of separation factors (5). We used mostly ^6Li for lithium since the cross-section for fusion of d with ^6Li is much higher than for ^7Li. However, the Li metal still contained 10% ^7Li.

If p + Li^6 signif't, than p + Li^7 much more likely

The surface barrier detectors were held at a reverse bias of 48 - 75 V to obtain about 100 μm of depletion. This is adequate for the detection of charged particles up to about 8 MeV. Particles with energies above this are still detected but some energy information is lost. The detectors were energy calibrated and tested using a standard ^{241}Am radioactive source.

The anode - cathode current was held at 150 mA/cm^2 for all of the reported studies. Ref. (1) indicates that observed nuclear products scale with current density, so we selected a current density near the high end of their range of values.

The above describes our experiment to detect CNF particles. All particle detectors have backgrounds, either due to trace radioactive materials in their fabrication, or due to cosmic rays interacting with the silicon. Ref. (3) reviews the background sources in silicon detectors and shows typical cosmic ray background rates. The rate we observed was statistically within the rate of this study. We note that we define "Background" as the spectrum observed with our experimental arrangement but with the cell current off. This assumes that there were no CNF particles generated while the cell was not in operation. Only one test was made of Background both before and after operation of the cell, and no change was observed.

The "incubation" or "charging" period for our cathodes to form β - Pd, Pd-hydride, will be shown to be less than 24 hours. Longer charging periods might be necessary for Li in the electrolyte to penetrate into the Pd. We accelerated this process by artificially injecting Li into two of the Pd cathodes. In one case Li was introduced by capsule diffusion at 600 C. A second cathode was ion implanted with Li; half the cathode was implanted with ^{6}Li (200 keV) to a dose of 10^{15} Li/cm^2, and the other half was implanted to 10^{16} Li/cm^2. Since we were looking for any kind of fusion, it was felt that having a mixed concentration of Li in the cathode would not compromise the experimental results.

Next to the cells were standard biological neutron monitors, and gamma detectors. These were used for personnel safety, and had thresholds of 0.1 mRem/hour.

As an independent evaluation of the "charging" of the Pd cathodes, the crystal structure of the Pd foils was determined by x-ray diffraction, using Zr-filtered Mo K_α radiation and a scintillation detector, with a Θ - 2 Θ diffractometer and symmetrical reflection geometry. Measurements were made for scattering angles, 2 Θ, from 90° to 155°.

EXPERIMENTAL RESULTS : All the experimental results are tabulated in Table 1. In no case was heat detected other than that caused by accountable electrical Joule heating of the electrolyte. Temperatures always remained below 45 C. At no time did the neutron or gamma detectors near the cells register radiation above 0.1 mRem/hour.

X-ray diffraction measurements were made on several of the Pd cathodes to evaluate the electrolysis time necessary to form β - Pd (above 60% hydrogen) from the normal α - Pd, and to determine the adequacy of the Au hydrogen-sealing layers on the cathode backs. A cathode with a 1.7um Au layer gave the diffraction pattern of α - Pd after 200 hours of electrolysis. The lattice parameter was 3.92 Å, somewhat larger than the published value for pure Pd (α - Pd), 3.89 Å.

Both thin (25um) and thick (0.5mm) Pd cathodes which were backed with about 6.3um Au films, after electrolysis for 24 hours, gave a pure β - Pd pattern with a lattice parameter of 4.03 Å, only slightly greater than the published value for Pd monohydride, 4.02 Å, see Figure 3. There was no evidence for any α - Pd in the diffraction spectrum. This result indicates that 6.3um of dense Au provided an adequate hydrogen seal to the back surface of the Pd cathode.

It is not clear whether the formation of β - Pd is essential for the reported CNF, so we report results from both types of samples.

One sample was pre-annealed to 900 C in a vacuum of 10^{-6} Torr for one hour. This anneal was intended to drive out any pre-absorbed hydrogen. The sample showed no unusual results.

CONCLUSIONS : Our experiment measured CNF particles with better sensitivity than that of (1) and (2). Our cell configuration was not identical to those of (1) or (2) since our cathode formed a thin window to allow the exiting of energetic charged particles. Our results show that no excess heat and no nuclear fusion products were detected for any of the samples tested. The partial substitution of H_2O for D_2O did not produce nuclear fusion products. Pre-annealing of the Pd cathode had no effect. The artificial introduction of ^{6}Li into the Pd cathode by either diffusion or ion implantation had no effect.

ACKNOWLEDGEMENTS : We wish to acknowledge the very valuable assistance of R. L. Garwin, P. Saunders, W. Kahn, F. Albert, J. Angilello, S. Burks, G. Dibello, W. Dimaria, E. Folsom, C. R. Guarnieri, H. Gertling, R. Gray, N. Penebre, S. Shivashankar, and C. R. Guarnieri.

TABLE 1

EXPERIMENTAL RESULTS

Sample Description	Electrolyte (D_2O/H_2O)	Duration of Run (hr)	Fusion Rate (Fusions/cm^3 sec)
F. & P. (Ref. 1) Neutrons	# 1	50	4000
F. & P. (Ref. 1) Observed Heat	# 1		10^{12}
Jones et al. (Ref. 2) Neutrons	# 2	8	0.7
			Particles detected (/cm^3 sec)
25 μm Pd + 1.7 μm Au Prebaked: 900C/1 hour/10^{-6} Torr Pure α-Pd after testing	# 1 (100/0)	205	< 0.0038
25 μm Pd + 6.5 μm Au Pure β-Pd after 24 hours	# 1 (100/0)	250	< 0.0052
0.5 mm Pd + 6.3 μm Au Pure β-Pd after 24 hours	# 3 (90/10)	24	< 0.00092
25 μm Pd + 6.5 μm Au	# 3 (90/10)	250	< 0.0051
25 μm Pd + 6.5 μm Au Pure H_2O Electrolyte	# 4 (0/100)	250	< 0.0054
25 μm Pd + 6.3 μm Au Diffused with ^6Li	# 3 (90/10)	127	< 0.0066
25 μm Pd + 1.7 μm Au Ion Implanted with ^6Li	# 3 (90/10)	73	< 0.0051

Electrolytes:

Elec. # 1 = 100 % D_2O with 0.1 molar LiOD. (really 99.5% D_2O)
Elec. # 2 = Electrolyte based on components of Earth's Mantle + Volcano Lava (see Ref. 2).
Elec. # 3 = 90 % D_2O + 10 % H_2O with 0.1 molar LiOD.
Elec. # 4 = 100 % H_2O with 0.1 molar LiOD.

Backings:

Pd foils were backed with Au films on the side away from electrolyte to prevent outdiffusion of hydrogen from the cathode (see text). Table 1 indicates the thickness of the sputter deposited dense Au films.

Calculation of detection limit:

In all cases the total signal counts (detected particles from 1 - 3 MeV) were within 3 σ of the background counts (taken with the cell current off), assuming Poisson statistics. The quoted particle upper - limit of detection is based on two σ of the Signal counts, without background removed, divided by the cathode volume.

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(6) Ref. (1) states their detected neutrons were three times background. M. Fleischmann has said their neutron signal after 50 hours contained 135 counts above background (private communication).

FIGURE CAPTIONS

Figure 1

Cross-section of the teflon electrolytic cell. The anode was always Pt, about 2 cm wide and 4 cm long. A $7cm^2$ conical hole in the side of the cell led to the $2cm^2$ cathode. The anode - cathode spacing was adjustable, but all tests reported here were at a spacing of 2 cm. The cathode was Pd foil of various thicknesses. About 2 mm behind the cathode was a surface barrier detector to measure energetic charged particles. The detector had a background for charged particles with energies of 1 - 3 MeV of about 5 counts / day (mostly due to cosmic rays).

Figure 2

Charged particle spectrum for a thin Pd cathode (25 μm thick, backed with 1.76 μm Au) during 205 hours of charging. Within statistics, all the counts are due to cosmic ray neutrons interacting with the silicon detector, see Ref. (4). The background of the detector was determined by making no experimental changes except for turning off the cell current. This background, taken over 82 hours, was virtually identical to the spectrum with the cell operating. The upper limit for the fusion rate for this experiment was .0038 fusions/cm^2sec.

Figure 3

X-ray diffraction spectrum from the 0.5 mm thick Pd cathode, backed by 6.3 μm Au. The peaks correspond to a lattice parameter of 4.03 Å, only slightly larger than the published value for Pd monohydride, 4.02 Å. There is no evidence of the original α - Pd metal in the spectrum. This leads us to conclude that complete hydrogenation of the cathode was obtained within the limits of the applied voltage and current density.

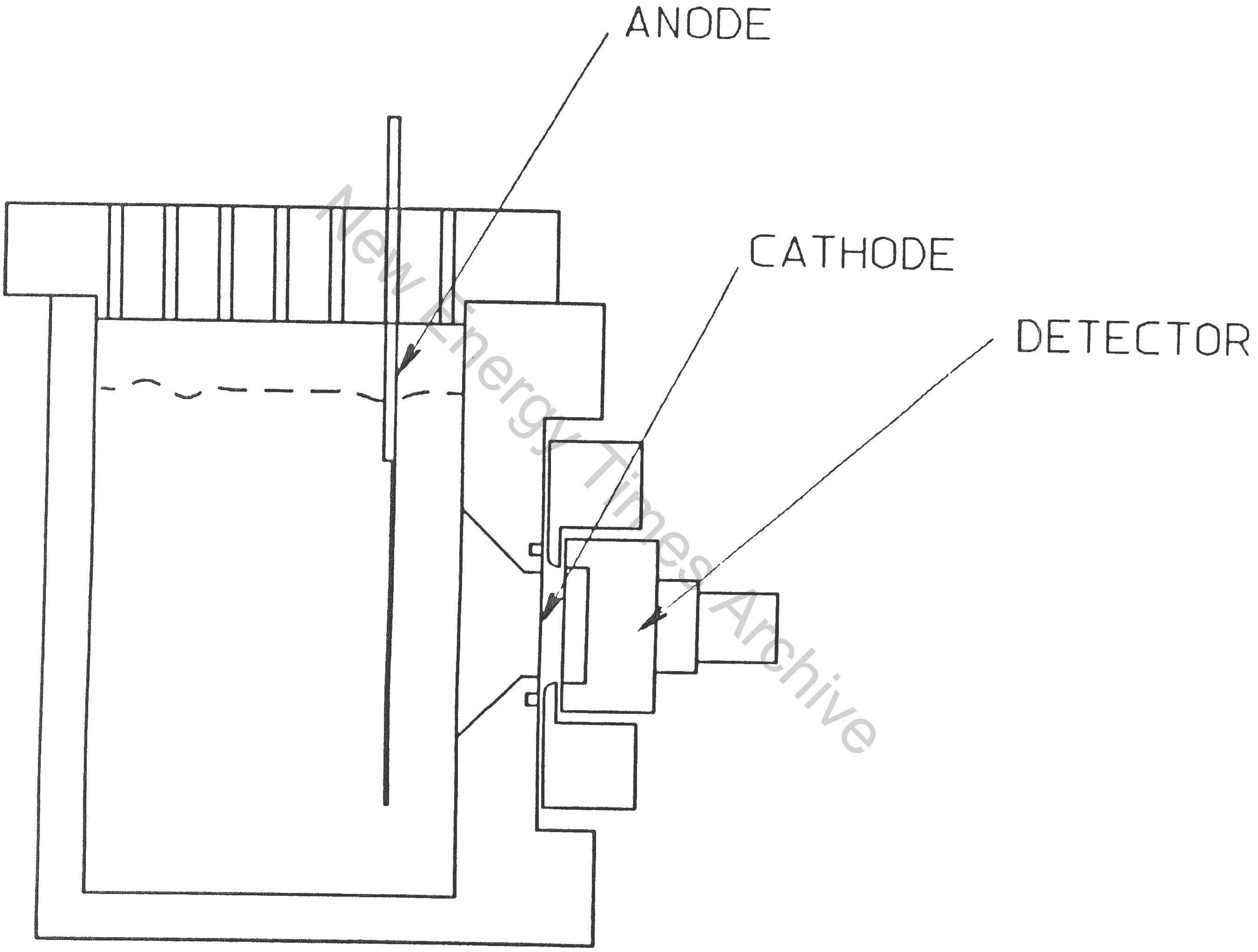

Fig. 1

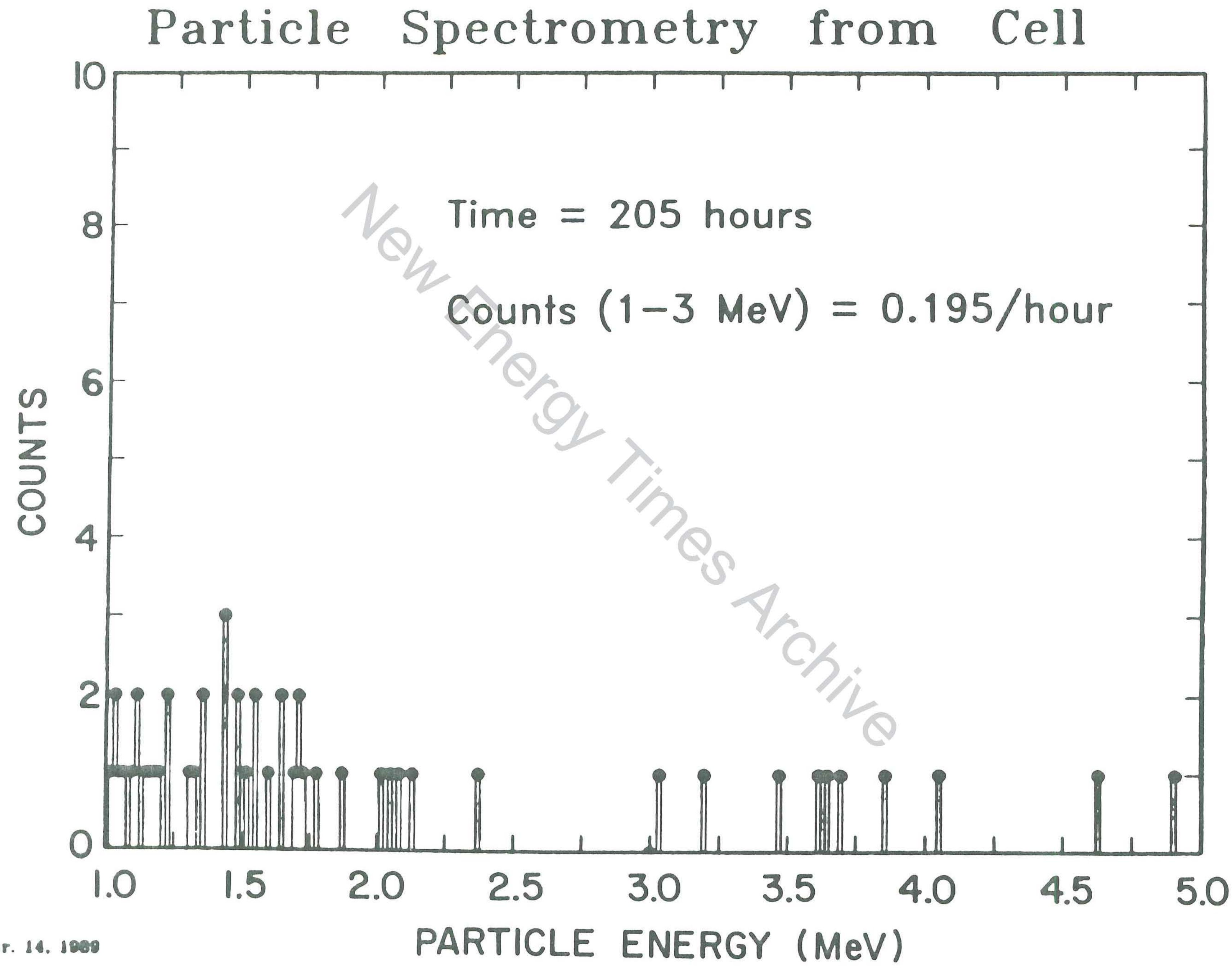

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Fig 2.

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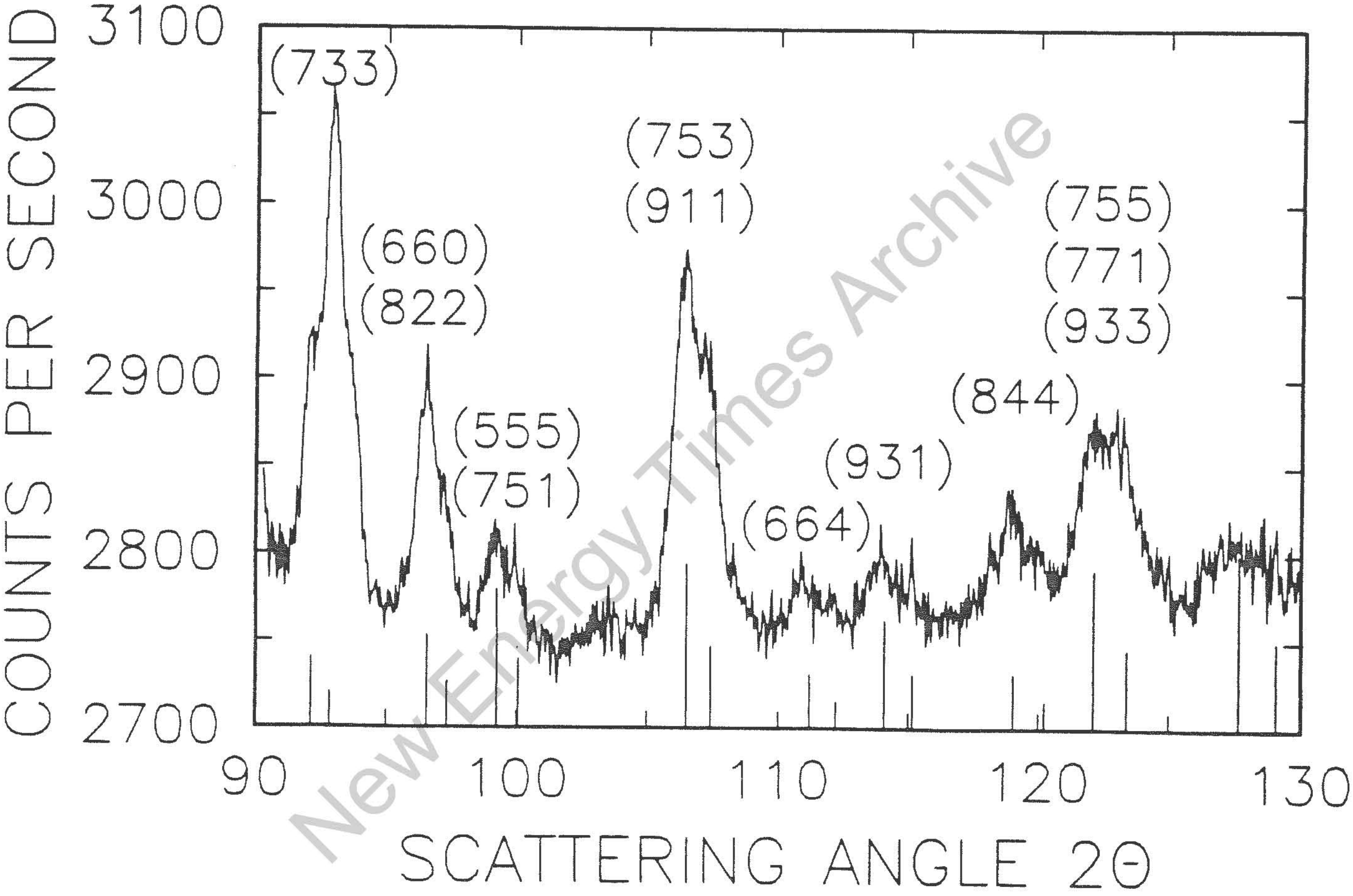
COUNTS PER SECOND
3100
3000
2900
2800
2700
90
100
110
120
130
SCATTERING ANGLE 2Θ
(733)
(660)
(822)
(555)
(751)
(753)
(911)
(664)
(931)
(844)
(755)
(771)
(933)

Fig 3.

WORKSHOP ON COLD FUSION PHENOMENA

NOTICE TO PRESENTERS

PLEASE COME TO THE WORKSHOP HEADQUARTERS LOCATED BEHIND THE STAGE (SEE ATTACHED DIAGRAM) APPROXIMATELY 15 MINUTES PRIOR TO YOUR SCHEDULED PRESENTATION.

AT THAT TIME, WE WILL COORDINATE YOUR AUDIOVISUAL REQUIREMENTS

SWEENEY CONVENTION MAIN FLOOR PLAN